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The Effect of an Abrasive Commercial Pearling Procedure on the Nutrient Content and Digestible Energy Value of Deoxynivalenol (DON)-Contaminated Hulled Barley for Swine

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ABSTRACT

Effect of commercial pearling on the nutritive value of DON-contaminated barley was determined using a commercial Satake™ pearling machine for 4 samples of DON-contaminated barleys: 1.2, 3.3, 5.5 and 7.6ppm. Barleys were subjected to 4 different levels of pearling: 1, 3, 5 and 7, respectively. After each pass, remaining grain were weighed for each sample and sub-sampled for DON remaining and gross energy (GE). Digestible energy (DE) content of the intact and pearled samples for each group was estimated using a published prediction equation for barley. After the 1st pass, 90, 90, 92 and 93%, respectively of grain mass remained with significant ($P < 0.05$) reductions in DON and fibre contents. The amount of grain remaining, %DON, %NDF and %ADF for the 4 groups after the 7th pass was: 67%, 23%, 28.5% and 13%; 68%, 9.9%, 30.7% and 17%; 71%, 7.4%, 38.6%, 18.7% and 70%, 11.7%, 41.6% and 17.6%, respectively. Crude protein (CP) contents were significantly ($P < 0.05$) increased after the 1st pass compared with the intact barley and more so for treatment 4 where improved CP was sustained up to the 5th pass. Ether extracts (EE), ash and GE contents linearly reduced as the levels of passes increased. However, there were significant ($P < 0.05$) improvements in the predicted DE content of the pearled barley with linear reductions in grain mass. The highest improvement was obtained after the 7th pass for all treatment groups. It was concluded that pearling is effective in reducing DON and fibre contents of DON-contaminated barley with increased predicted DE value.

Key words: DON-Contaminated Barley, Pearling, Nutritive-Value and Swine

1. INTRODUCTION

Mycotoxins are byproducts of fungi (*fusaria*) metabolism in crops in the field during production and in storage. There are many species of *fusaria* that produce

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mycotoxins. However, deoxynivalenol (DON) also known as vomitoxin produced by *Fusarium graminearum* is most ubiquitous and mainly responsible for the observed toxicological impacts of mycotoxins in swine and poultry probably due to *F. graminearum* ability to produce more than one mycotoxin (ApSimon, 1994; Tekauz *et al.*, 2000). Barley is used primarily as an energy source in swine diets (NRC, 2012). The presence of DON in grains, such as barley leads to substantial economic losses through reduced grain quality as it relates to the feeding of livestock, particularly swine (Dersjant-Li *et al.*, 2003).

Swine are very sensitive to the presence of DON to the extent that DON level above 1 ppm in their diet results in feed refusal, emesis and thus reduced growth rate because of the toxic effects of DON (D'Mello *et al.*, 1999; House *et al.*, 2002). Other independent studies had also demonstrated these negative metabolic effects of DON when present in swine diets above the recommended level leading to longer time for animals to reach market weights (Abramson *et al.*, 2005) resulting in considerable attendant losses of revenue to the hog farmer. This has resulted in the search for means of removing DON from barley grain intended for swine feeding.

DON is usually found in the exterior sections of barley kernel where infection begins and later spread around the outer portions mainly with little or no penetration into the inner kernel (Lee *et al.*, 1992; House *et al.*, 2003). Therefore, for a strategy to be effective in removing DON from DON-contaminated barley it should primarily targets the sections dominated by DON in the barley grain. Accordingly, amongst the methods studied to be effective in removing DON is by de-hulling or polishing away the DON-dense layers of the DON-barley. De-hulling is the process by which the DON-contaminated barley is brought into contact with an abrasive rotating disk such that the outer portions with more of the DON concentrations are polished away. This has been proven using a small scale laboratory de-huller (House *et al.*, 2003). Nevertheless, barley is usually used in bulk during diet formations; therefore, there is a need to evaluate the efficacy of the pearling process at a commercial level. Furthermore, there is a need to also assess the impact of pearling on the nutritional profile of pearled DON-barley in order to better characterize its usefulness as a feed ingredient for swine. This would enhance the utilization of locally produced barley and thus mitigate against losses associated with DON-accumulation in barleys destined for the swine industry. This would also help to avoid importation of barley into a region or area known for barley production and thus add value to DON-contaminated barley. Therefore, the objectives of this study are: to determine the efficacy of DON removal from DON-contaminated barley using an abrasive commercial Satake™ pearling machine and to assess the impact of commercial pearling on the DE value and other nutrient components of DON-pearled barley.

2. MATERIALS AND METHODS

Barley acquisition and treatments

Two DON-barley samples: low in DON (1.2ppm) and high in DON (7.6ppm) were acquired from local farmers for the study. The levels of DON in the two barley types were confirmed by DON assay prior to commencement of trial. The low DON-barley and the high DON-barley were mixed using Marion Mixer (Rapids machinery company, Marion, Iowa, USA, Model No, 2010) for 10 minutes to produce two synthetic DON-barley gradient types as: 67% versus 33% (mixing ratio of 2.03: 1) resulting in a synthetic DON-barley sample of 3.3ppm and 33% versus 67% (mixing ratio of 1: 2.03) resulting in another synthetic DON-barley sample of 5.5ppm, respectively. This resulted in 4 treatment levels of DON-barley samples of: 1.2, 3.3, 5.5 and 7.6ppm, respectively used in the study.

Pearling Procedure

For each DON-barley group two replicate samples of 50kg each were subjected to a sequential abrasive removal of the outer portions (hulls) using the commercial Satake™ pearling machine (Satake RMB 10G Rice Polisher) according to the method of House *et al.* (2003). As samples were passed through the machine they came into contact with an abrasive pearling rotating disk at four different levels: 1st, 3rd, 5th and 7th, respectively. At each of the passing stages all factors were held constant. For instance, after all grains have passed the machine at each stage of pearling a constant time interval of 1 minute was allowed before turning off the machine. At each pass, the barley was sub-sampled. Sub-sampled amount was accounted for when calculating the percentage of the original mass remaining by weight.

The sub-sampled barley fractions at each pass and their intact barley counterparts were subjected to chemical analyses that formed the basis for comparisons of the impact of commercial pearling on the estimated DE content and other proximate components: CP, ash, EE, NDF, ADF and GE. Sub-sampled fractions were used as the basis for DON removal from barley. Also, the weight of grain mass remaining after each pass was used to calculate the percentage of grain remaining after polishing in reference to the initial 50kg.

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Chemical Analyses

Samples of intact and pearled barleys were analyzed for DON content by the enzyme immunoassay method (RIDASCREENR DON, Art. No. R5906, R-Biopharm AG, Darmstadt, Germany). CP (N x 6.25) using the LECO CNS-2000 Nitrogen Analyzer (Leco Corporation, St. Joseph, MI, USA, Model No. 602-00-500), ash was analyzed according to standard procedures (AOAC, 2000). GE was determined using an Adiabatic Bomb Calorimeter (Parr Instrument Company Inc. Moline, Illinois, USA). NDF and ADF were determined by the Akom procedure and EE was determined by extraction using hexane. DE values for the different barleys were estimated using a published equation for barley in swine feeding (Fairbairn *et al.,* 1999); where DE = 3,526 – 92.8 x %ADF. The initial values for DON, proximate components and energy are shown in Table 1.

Table 1. DON content, Proximate Analyzes and Estimated DE content of Barley Samples Prior to Pearling[a]

	Treatments			
Item	1	2	3	4
DON (ppm)	1.2	3.3	5.5	7.6
CP (%)	11.61 (0.06)	11.41 (0.03)	11.36 (0.04)	11.11 (0.04)
Ash (%)	1.97 (0.01)	2.34 (0.06)	1.99 (0.09)	2.41 (0.3)
EE (%)	2.57 (0.7)	1.94 (0.09)	2.10 (0.1)	1.85 (0.09)
NDF (%)	17.41 (1.4)	17.32 (1.1)	17.10 (0.3)	17.06 (0.4)
ADF (%)	5.91 (0.03)	6.03 (0.08)	6.67 (0.1)	6.48 (0.5)
GE (kcal/kg)	4,092.8 (9.1)	4,067.9 (8.8)	4,033.7 (5.2)	3,971.8 (8.8)
DE (kcal/kg)	2,977.6 (2.6)	2,966.4 (7.9)	2907.0 (12.5)	2924.7 (48.6)

[a]Values are means (SD) of two replicates; Treatments 1 to 4 contained 1.2, 3.3, 5.5 and 7.6ppm of DON, respectively.

Statistical Analyses

For each barley treatment, DON, proximate components and energy obtained following pearling were expressed as a percentage of the initial values. Data were subjected to analyses of variance (ANOVA) with main effects partitioned between pearling (passes), treatment and the interaction term. Individual treatment means were compared to control (intact barley) values set at 100% using Bonferoni's test with adjustment for the number of comparisons using the Proc GLM of SAS (SAS Institute Inc. 1988). The model was $Y_{ijk} = \mu + T_i + P_j + T_iP_j + E_{ijk}$: where Y_{ijk} = the effect of pearling on the kth barley in the ith treatment in the jth pass, μ = the population mean, T_i = the effect of the ith treatment, P_j = the effect of the jth pass, T_iP_j = the interaction term between treatment and pass, E_{ijk} = the residual error. The level of significance was at $\alpha = \leq 0.05$.

3. RESULTS

Commercial pearling procedure which involves the placing of the contaminated grain in contact with a rotating abrasive disk proved to be an effective strategy of decontaminating DON from DON-contaminated barley. Additionally, is an effective means of removing fibre components of the DON-contaminated barley. As shown in Table 2, the 3rd level of pearling proved to be the most efficient and of best nutritional advantage of pearling DON-contaminated barley intended for swine feeding. At this level, the removal of about 18 – 20% of the contaminated grain mass resulted in the removal of about 65 to 82% of the DON, 40 to 54% of NDF and 62 to 78% of ADF, respectively. It was the level with the minimal loss in grain mass with significant ($P < 0.05$) improvements of 18 to 20% in DE values of the pearled barley compared to their intact samples (Table 3). Similarly, it was at the 3rd level of pearling that CP content was significantly ($P < 0.05$) elevated over the intact value, particularly for the heavily contaminated barley sample (treatment 4) by 6.2%. Nevertheless, increasing the pearling level resulted in more reductions in DON and fibre with further increase in the DE contents of pearled barley with more losses in the grain mass primarily due to the sustained reductions in NDF and ADF (Fairbairn *et al.,* 1999). Ash, EE and GE contents reduced just like DON as pearling level increased. Again, these findings demonstrate that commercial pearling is an effective means of improving the nutritive value of DON-contaminated barley, especially as it relates to DE content of pearled barley (Table 3).

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Table 2: Effect of Pearling (passes) on Grain mass, DON removal and Nutrient Profile of Barley

Treatment	Pass(es)	Grain mass	DON	CP	Ash	EE	NDF	ADF	GE
			% of original values						
1	1	90*	56.5*	103.6*	87.8*	86*	54.6*	50.6*	99.7
1	3	80*	34.9*	93.9*	57.1*	63.4*	45.9*	26.4*	98.7*
1	5	73*	23.2*	88.6*	55.8*	52*	32.1*	15.1*	98*
1	7	67*	22.5*	84*	37.6*	43.8*	28.5*	13.2*	97.7*
2	1	90*	60.9*	102.5*	82.5*	98.7*	70*	60.4*	99.8
2	3	80*	18.7*	101.5	55.1*	87.4*	48.4*	22.2*	99.1
2	5	74*	12.2*	95.2*	52.6*	62.1*	42.3*	19.6*	98.4*
2	7	68*	9.9*	88.5*	39.1*	53.9*	30.7*	17.3*	97.8*
3	1	92*	41.8*	102.8*	84.2*	98.1*	75.1*	65.2*	99.7
3	3	82*	15.2*	101.8	64.5*	94.5*	55.2*	27.4*	98.7*
3	5	76*	9.1*	96.8*	55.6*	75.6*	45.6*	21.4*	98.3*
3	7	71*	7.4*	91.3*	46.7*	67.7*	38.6*	18.7*	97.7*
4	1	93*	71*	103.7*	89.1*	96.7*	88.4*	92.9*	100.1
4	3	82*	31*	106.2*	70.7*	95.7*	60.3*	38.4*	99.9
4	5	76*	16.4*	102.3*	62.2*	90.5*	47.4*	28.1*	99.8
4	7	70*	11.7*	96.6*	56.2*	80.3*	41.6*	17.6*	99.2
SEM[c]		0.2	0.1	0.8	1.6	0.1	0.2	1.1	0.1
Passes (P)		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Barley (B)		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0013	<.0001
P x B		<.0001	0.0005	<.0001	<.0001	<.0001	0.0012	0.0866	0.0019

[c]SEM = standard error of the mean. *signifies that values within a column are significantly ($P < 0.05$) different from 100% using Bonferoni's test. Treatments 1 to 4 contained DON at: 1.2, 3.3, 5.5 and 7.5ppm, respectively, prior to pearling.

Table 3. DE values of intact and pearled DON-contaminated Barley

Pass(es)/Pearling	1.2 ppm	3.3 ppm	5.5 ppm	7.6 ppm
	DON-Contaminated Barley Treatments			
0 (kcal/kg)	2978	2966	2907	2929
1 (kcal/kg)	3479*	3470*	3465*	3438
3 (kcal/kg)	3502*	3505*	3501*	3491*
5 (kcal/kg)	3512*	3508*	3506*	3500*
7 (kcal/kg)	3514*	3508*	3509*	3510*

*Signifies that values are significantly ($P < 0.05$) different from the intact barley

4. DISCUSSION

The pearling procedure in which DON-contaminated barley is brought into contact with a rotating abrasive disk of the commercial Satake™ pearling machine for controlled periods proved to be an effective strategy of removing DON from DON-contaminated barley. There is relatively high intake of cereal crops in the diets of farm animals, particularly swine. Therefore, DON in cereal grains poses serious safety implications for cereal crops, hog producers, grain handlers, food and feed processors, consumers globally and eventually national economies (Clear and Patrick, 2003). During seasons or periods of heavily contaminated grains, such as the 'so called *fusarium* years', such barley with DON; the use of such gain in swine diets become extremely difficult. To this end, the development of a strategy for dealing with DON remains a viable option during such periods. DON is chemically stable and survives food processing thereby posing serious health hazards to animals' and human health and the only viable option is to have DON removed or at least reduced to levels animal can tolerate in their diets (Tekauz *et al.*, 2000).

Since DON was identified by Morooka *et al.* (1972), it has been established that its toxicological impacts on any livestock are dependent on such processes as absorption, distribution, accumulation, metabolism and the ability of the species to eliminate DON

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(Rotter *et al.* 1996). A wide range of sensitivities exists to DON amongst the different animal species. Swine had been identified as the most susceptible species as pigs can display decreased feed consumption at concentrations as low as 3-4 ppm DON (mg pure DON/kg diet) in their diets. However, other species, such as ruminants and poultry had been shown to easily tolerate ≥ 20 ppm DON (Rotter *et al.* 1996) without severe impediments to performance. This is mainly due to the ability of other species to detoxify DON, particularly ruminants (Rotter *et al.* 1996; Abramson *et al.*, 2005). The general order of decreasing sensitivity has been acknowledged as pigs > mice > rats > poultry > ruminants (Rotter *et al.* 1996; Abramson *et al.*, 2005). This demonstrates that the toxicological impacts of DON are most severe in swine and more so with immature swine (Rotter *et al.* 1996). Consequently, the consumption of DON-containing diets by swine results to delayed time taken for animals to reach ideal marketing body weights reduced feed efficiency, immunosuppression, organ damage and overall quality loss (Charmley *et al.*, 1994). These also result in reduced animal performance and increased disease incidence, including higher morbidity and mortality rates may be evident. This is where the novelty of the pearling technology as found in this current study becomes handy. The technology converts hitherto barley that cannot be used in feeding swine to an 'acceptable' feed ingredient for swine as a result of its efficacy on DON removal.

Clear *et al.* (1996) and McCallum *et al.* (1999) demonstrated that DON concentrates mainly in the exterior layers of the contaminated barley and therefore, for a strategy to be viable in managing DON it should involve the polishing of the hulls where DON is mostly found in the grain leading to high concentrations of DON in the brans obtained after the polishing process. In this study, at the 3rd pass resulting in the loss of 18 – 20% of grain mass more than 50% of DON in the barleys was removed irrespective of the initial level of DON in the barleys. It is also at the 3rd pass that DON levels significantly ($P < 0.05$) dropped for all the treatment groups. This observation confirmed that it is this level of pass that is more beneficial in the use of the commercial pearling in managing DON in DON-contaminated barley for use in the swine industry. It was also the level CP was still intact or significantly ($P < 0.05$) improved above the initial value. These findings are in agreement with those of Lee *et al.* (1992) and House *et al.* (2003).

In addition to DON removal from DON-contaminated barley, another nutritional advantage of pearling of DON-barley destined for feeding farm animals, especially swine was in fibre reductions. Fibres are anti-nutritional factors for non-ruminants, since they are deficient in cellulases that degrade them (NRC, 2012). Apart from the inability of pigs to digest fibres, fibres prevent the digestibility of other nutrients by causing digesta viscosity and diluting energy content of the diet (Fairbairn *et al.*, 1999; NRC, 2012). The findings of fibre reductions in this study via pearling are also in agreement with those of Fairbairn *et al.* (1999), Moeser *et al.* (2002) and House *et al.* (2003). Therefore, the significant ($P < 0.05$) improvements of the DE of pearled barley over their intact counterparts was not surprising as they are related to reduced levels of fibres in the pearled barleys. Earlier studies (Patience *et al.*, 1995; Thacker and Bass, 1996) had suggested that one of the ways to increase the energy content of barley for pigs would be by de-hulling. The premise to this suggestion possibly could be due to the fact that de-hulled barley would contain less fibrous hull fractions and therefore give rise to increased digestible energy value of barley for pigs, especially the immature pigs. These hypotheses remain to be confirmed in the use of de-hulled barley in the nutrition of pigs, particularly the immature swine in in vivo studies.

5. CONCLUSION

The implication of the finding of this study is that heavily DON-contaminated barley up to 7.6ppm if first pearled by way of 3 passes through the commercial Satake™ grain abrader can turn such barley into an acceptable ingredient for swine. Therefore, it is inferred that commercial pearling using the Satake™ pearling machine is effective in de-hulling DON-contaminated barley to remove or reduce DON content of such barley for swine feeding. Additionally, the pearling resulted in the improvements of the DE value of the pearled barley. Nevertheless, from the results obtained in this study further research is warranted to better elucidate the cost implications of the improvement in the DE value of DON-contaminated barley as energy is the most expensive component in swine diets. This would help to assess the costs implications between converting DON-barley by the pearling technique to the importation of 'DON-free' barley into any DON endemic region. These findings also need to be confirmed or tested by in vivo studies.

Recommendations

Based on the summary of findings and conclusion of this study, the following were made to enhance Inland water transport in Borgu LGA.

1. There should be the provision of a life jacket and other safety equipment for users and operators to enhance safe delivery in the course of conveyance.

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2. There should be financial assistance for the operation of inland water transport in the Borgu LGA. The government should intervene by the provision of funds to the boat's operator.
3. Adequate maintenance of boats should be encouraged, through the enlightenment of operators and location of a workshop near the water shore for easy accessibility.
4. The boat should be easily accessible by users to ease their day to day activities, through the construction of motorable roads and regular maintenance for sustainability.
5. There should be active and effective regulatory law and agency on the ground, to supervise the compliance of boat operators in the Borgu LGA. From fare regulatory, safety compliance, and the number of passengers to be carried.
6. Search and rescue team is highly needed to be at standby to rescue people in case of boat mishaps/ accidents during transportation. The government can provide fly boats and the operators too and liaise to put them in place to rescue mishaps.

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Conflicts of interests

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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